Limitations on Energy Deposition in Solid and Liquid Targets and Jet Liquid Target Description.

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Target problems are among the important as in the current runs of TEVATRON collider so in the most degree in its upgrades [1]. Focusing of 5*10**12 protons onto a target in a spot of =0.15 mm size will provide the deposed energy density of 1.5 kJ/gr in a copper target and of 3.2 kJ /gr in that of tangsten. To present time sufficient experimental data are stored in FNAL so as in CERN concerning to target material destracture caused by intensive proton beam. Let us try to understand the nature and features of such a destructure considering the material behaviour from the hydrodynamical point of view which represents the most common lows of material transformation, that of mass, energy and momentum conservation, and is quite admissible if values of preassure exceed the fluidity limit.

Energy deposition in target material leads to a rise of preassure in the region where such a deposition takes place, thus inciting a compressive wave propagation into the outer space. Simultaniously the decompressive wave propagates into the region of energy deposition from its boundary to the center.The preassure in decompressive wave can fall below zero and if this negative preassure exseeds the limit of material stability for expansion, the destruction occures.The stability limit is determined by the Brinell hardness H_B of material [2].

In the acoustic approach to the hydrodynamical consideration with the equation of state in simple empiric form

$$E = E_c + E_T$$

$$P = -\frac{dE_c}{dV} + \frac{\Gamma E_T}{V},$$

where E is the specific value of internal energy, $E_c = \frac{C_0^2}{2}\left(1-\frac{V_0}{V}\right)^2$ and E_T - its potential and thermal components,V - specific volume of material, Γ - Gruneisen coefficient, C_0- sound speed, the value of preassure P at the beam axis not too close to inlet or outlet target surfaces is determined as:

$$P = \frac{\Gamma Q_0}{C_0 V_0 \tau}\left\{\int_0^{C_0 t} e^{-\frac{C_0^2 t^2 - x^2}{2\sigma^2}}\,dx - \int_0^{\max\{0,\,C_0(t-\tau)\}} \exp\left\{-\frac{C_0^2(t-\tau)^2 - x^2}{2\sigma^2}\right\}dx\right\} \quad (1)$$

where Qo stands for specific value of deposed energy at the center of its trasverse distribution which is considered gaussian with r.m.s. width σ, while the longitudinal distribution of energy and time structure of particle beam are considered homogeneous. Duration of beam spill onto the target is denoted by τ. Expression for E is empiric one taken from[3].

At a fixed value of Q the preassure depends significantly on τ. It is maximum, if τ is much shorter than a time t_h of sound propagation across the region where the energy deposition takes place. Its value then is $P = \Gamma Q/Vo$ and decompressive preassure achieves the value of $(-P)max = 0.285\ \Gamma Qo/Vo$.

If spill duration is large as compared to t the values of preassure are about t_h/τ times less, than in the case where $\tau \ll t_h$. The maximum decompressive preassure at the beam axis is

$$(-P)max \cong \frac{\Gamma Q_o}{V_o} \cdot \frac{\sigma}{1.19(C_o\tau + 1.19\sigma)} \qquad (2)$$

If beam consists of a series of bunches with intervals much shorter than t_h, its time structure could be considered as homogeneous.

At fig.1 the decompressive preassure in tungsten target for the proton beam parameters such as in the corresponding run (r.m.s. beam spot size σ_ℓ = 0.28 mm) is shown versus Qo in comparison with the hardness H dependence on temperature. The value of σ for energy density distribution is taken equal to σ = 0.7 mm that fits the calculated data [4], spill duration is 1.67 mcs. Two curves of H_β per temperature represent two kinds of tungsten - a hard and an annealed ones. In both cases the itersection with line (-P)max versus Qo, that determines the limit value of energy density, takes place near Qo = 200 J/gr in an exelent harmony with experimental data. Another conclusion from the above consideration - the localization of material damage within the region of energy deposition, where high temperature and negative preassure take place simultaneously, also well agrees with experimental evidence.

In the case of copper target the hardness value and its reduction with temperature are strong dependent on type of copper. At fig.2 the H versus temperature is shown for one of them - C92260. Here the hardness falling down with temperature rise up to about 100°C, keeps almost constant value of H_β = 57 kg/mm at higher temperatures, thus predicting the limit value of Qo being of the order of 460 J/gr for energy distribution width σ = 0.6 mm whichB comes from [4] for beam width of a current run σ_ℓ = 0.18 - 0.20 mm. It is not in bad accord with the value Qo = 420 - 370 J/gr following out of [4] for current run with 2*10**12 protons per spill.

Mechanical limit for energy deposition density in copper target looks to be able to increase if a proper type of copper would be chosen among the multitude of them, some having the twice or so higher value of H than used in above evaluation, however it would hardly permit to exceed the melting energy - the sum of energy for heating up to the melting point and the latent melting energy - equal to about 680 J/gr.

In the liquid target the main limiting factor is the so called mass depletion effect, i.e. the significant decreas in target density during beam spill in the region of beam travel. From that point of view the severe limitation arises to a choise of target material. Nor mercury looking so proper nor lead could be taken because of early start of mass

deplesion. The ehergy density per proton in lead is close to that in tangsten, i.e. it is to be of the order of 2 kJ/gr already after the phase I of accelerator upgrade fulfilment. By that the material density at the beam axis will decrease to the end of beam spill in more than five times from its initial value. As to the mercury where the energy density would be of the same order,it should be evaporated during the first quorter of beam spill. So the only materials which meet the targeting conditions are that with high energy of sublimation and low enough melting point. The gold and the copper seem to meet both these requirements.

In copper the density ρ dependence on specific value of energy deposition at the beam axis is well discribed by the expression (3) [5]

$$\rho = \rho_0 \, e^{-\Gamma Q_0 / C_0^2} \qquad (3)$$

With Qo equal to 1.5 kJ/gr density reduction to the end of beam spill will be equal to 18% that means about 10% loss in the medium density.

Crutial value of Q may occures to be that corresponding to store of about a half of the latent energy of vaporization. Near this point the value of d^2E_c/dV^2 ,where $E_c(V)$ is internal potential energy of material, changes its sign that means the attractive forses in material begin to weaken with an increase of specific volume. It may results in an instability of liquid metall jet under the beam exposure.

If gold is considered as a material for liquid target the specific energy per proton should be about the same as in tungsten,i.e. two times more than in copper and accordingly more will be the mass depletion effect. Moreover, the energy for vaporization ,including heating from melting to boiling point and the latent energy of vaporisation, is about 2.1 kJ/gr only and 3 kJ/gr energy deposition will be much above admissible.

So the heavy metalls, having high density of energy deposition, looks to be of no good as concerning the mass depletion effect. They are nevertheless of much use for the cases where not the deposed density of energy per spill but that of medium power is high, so as it occures in the electron - positron conversion systems operating at high repetition rate.

Development of jet liquid targets is now in progress in the Institute for Nuclear Physics in Novosibirsk [6]. The technology is practically worked out for target of Ga-In alloy, whose melting temperature is 18°C only. Such a target made as a flatt jet of liquid metall flowing with a stationary velocity of several meters per second was already produced and sent to IHEP in Protvino for tests under the proton beam. The scheme of target device is shown in fig.3. It consists of vacuum chamber with electromagnetic pump and drain cavity with a nozzle of 25 cm length which the metall jet is draining through. Jet thickness could be changed from one to several millimeters by changing the width of nozzle. Full volume of liquid metall in system is equal to 500 cubic cm. The system could be heated up to several hundreds degree thus allowing to try the materials with higher melting temperature. The conditions for optimum

operation efficiency of Ga-In system were studied and test run during 500 hours was worked out before the system was sent to IHEP. These conditions include the filling of the system with an inert gas of the purity of 10 - 100 ppm under a preassure of about 1 atmosphere. At present the system is under a preparation for the test with proton beam.

The same design scheme was adopted for the development of system for high ,more than 500°C, operating temperature but its size is to be made as small as possible and as a material of its manufacture of is chosen the graphite. Graphite is high temperature and chemically resistive,and transperent for magnetic flux that is necessary for proper operation of our pumps.At present the technology for super strong materials production at the base of graphite fibres and fabrics is in good progress in the industry. Elaboration of technology of graphite chamber production is carried on in collaboration with Moscow institute NIIGraphite.

The scheme of target device is shown in fidure 4. Its outer size is about 100*120*120 mm. The optimisation of geometry was fulfild on a chamber of organic glass with liquid Ga-In alloy. That permitted to watch the way of metall flowing through the system. At present the geometry is mainly chosen and chamber of graphite is manufactured. Nozzle length is 50 mm and width is variable from 0.5 to 2 mm. The nearest plans are to test the system with liquid lead.

First version of high temperature target device will not have an aperture for beam to go in and out. Beam will pass through 5 - 10 mm thick graphite walls or through windows in it closed with titanium or berillium foils.

In its final version the target device, put into vacuum chamber with special system for gas evacuation and with inputs for pump feeding, will be placed on an ajusting mechanism with distant two coordinate replacement under the beam. The pump is fed from a special thyristor invertor operating with 2 kHz freaquency.

References

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Figure captions

Fig.1. Hardness H_B and the maximum destructive preassure versus energy density deposition in tungsten.

Fig.2. Hardness H_B of copper C92200 in dependence on temperature.

Fig.3. Stationary jet target. 1 - observation window,2 - beam axis, 3 - drain chamber, 4 - nozzle, 5 - liquid metall, 6 - pump.

Fig.4. Jet target device of graphite. 1 - liquid metall, 2 - graphite chamber, 3 - pump, 4 - strenghten pump carcass, 5 - thermoinsulating screen, 6 - coil of electromagnet, 7 - magnet flux conductor, 8 - ceramic supports, 9 - drain chamber, 10 - magnet plug, 11 - chanells for flux conductor introduction.

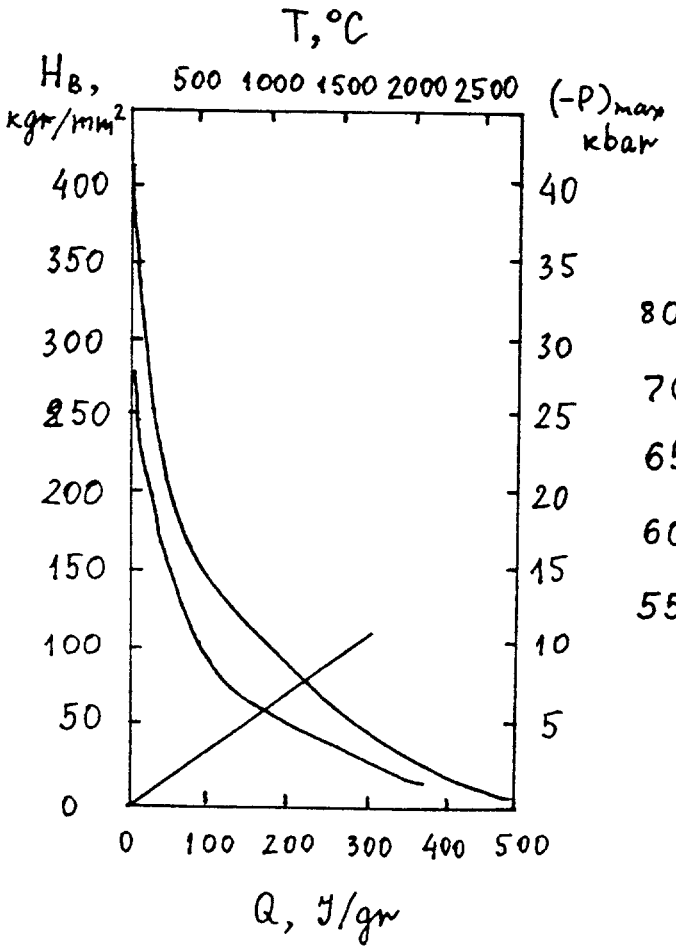

Fig 1.

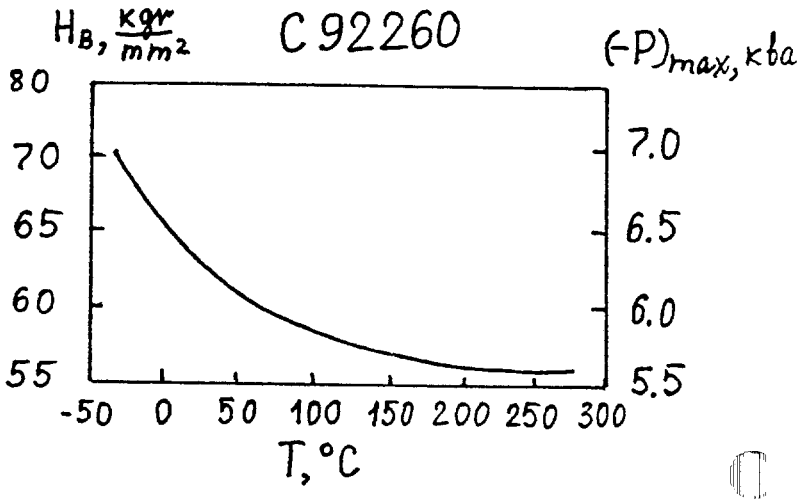

Fig.2

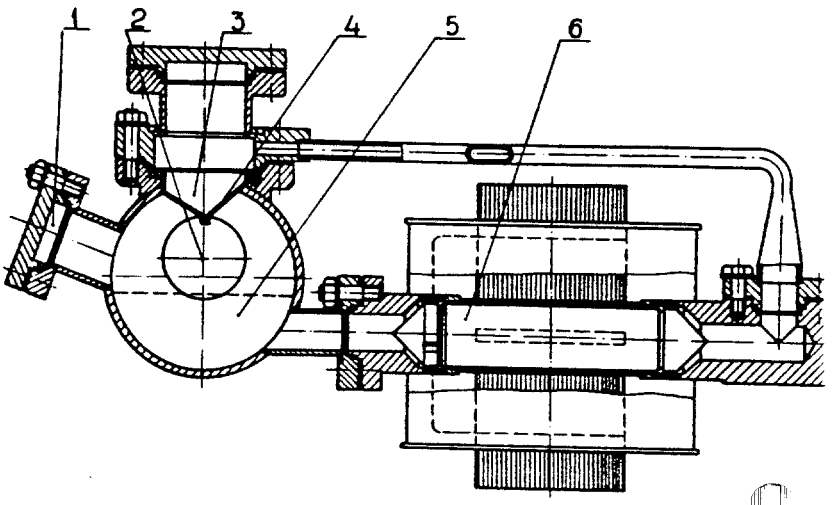

Fig. 3

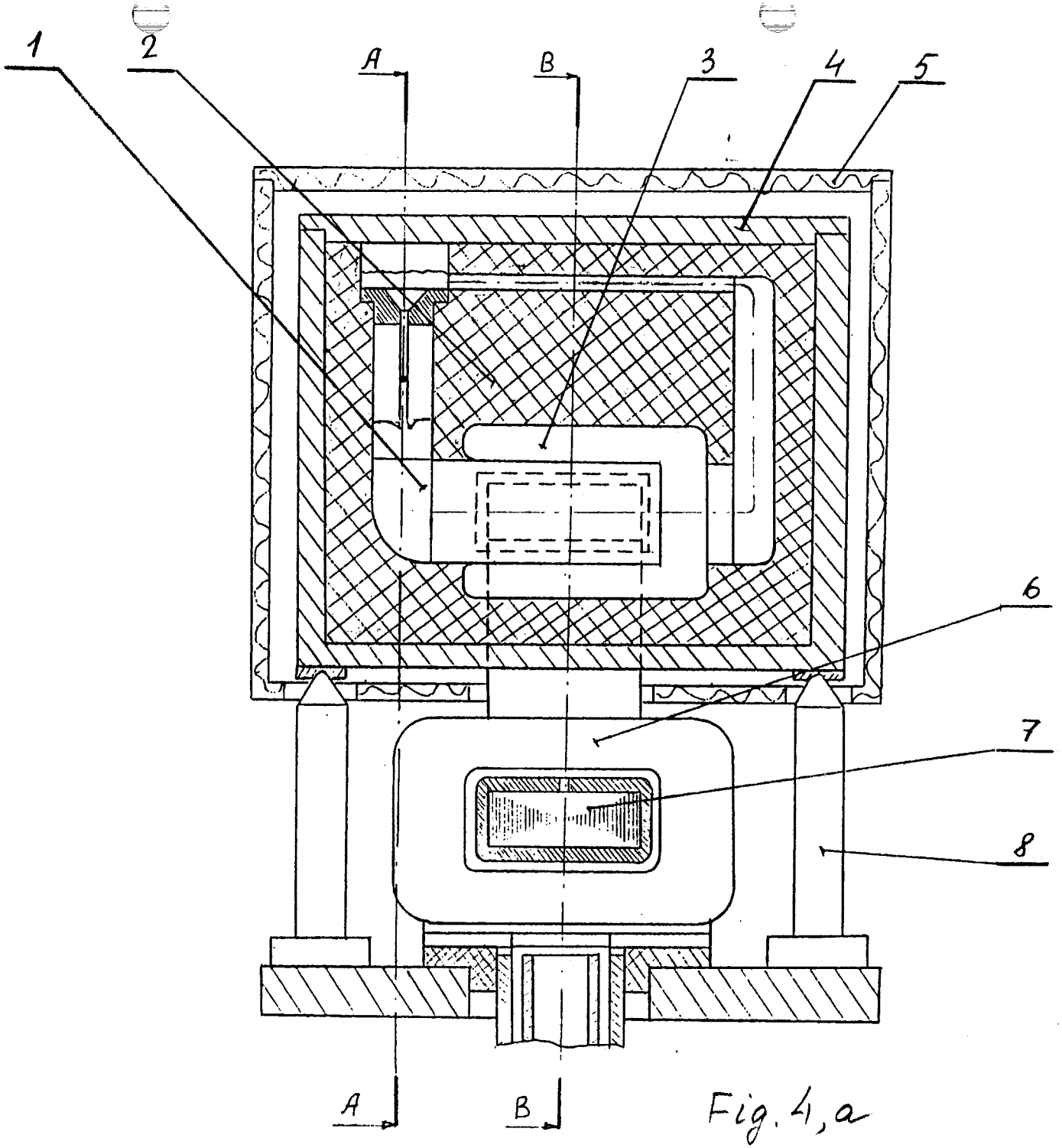

Fig. 4, a

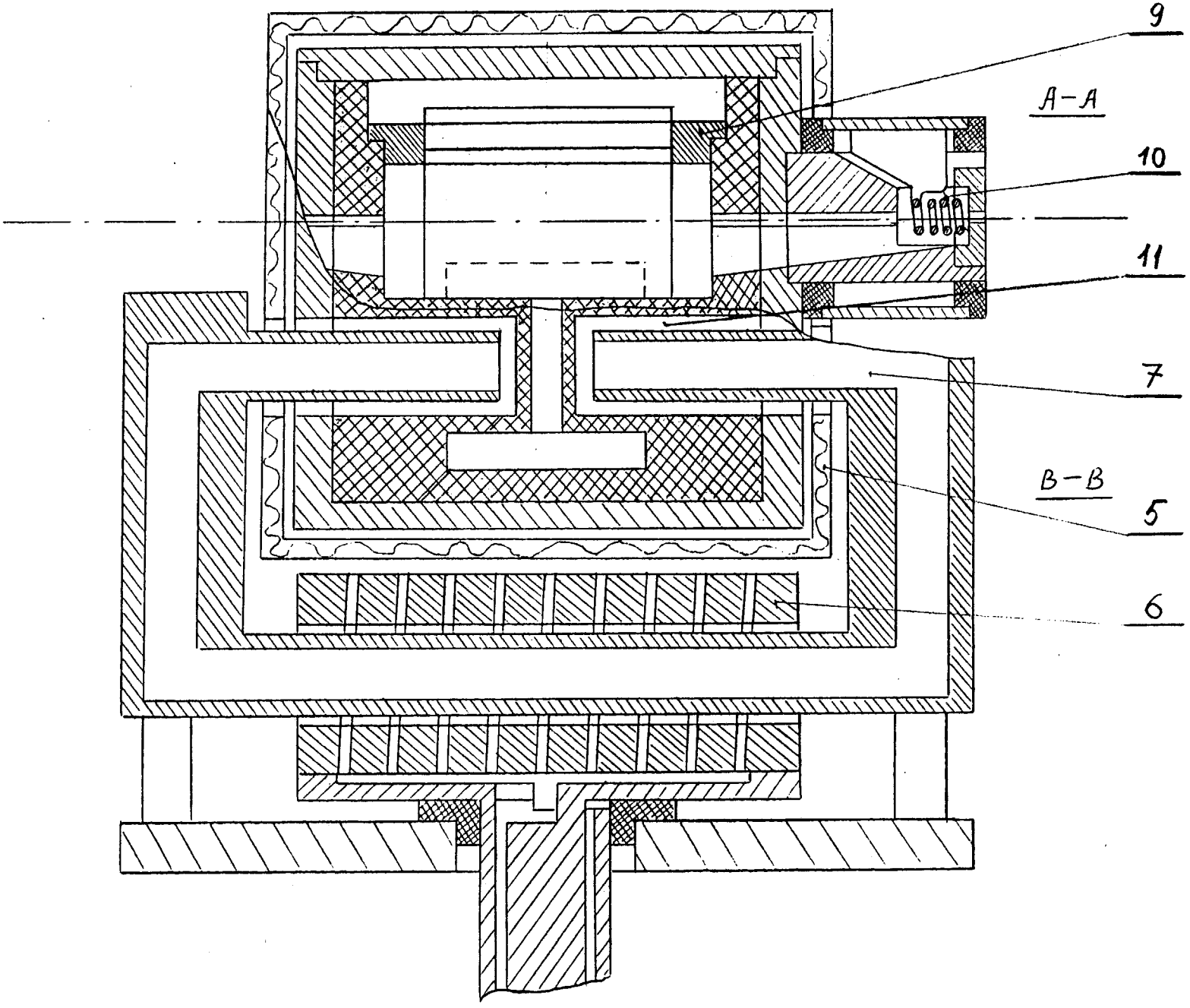

Fig. 4, 6